MEASUREMENT

Effect of increasing heart rate on Doppler indices of left ventricular performance in healthy men

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Abstract

***Objective*—To investigate the effects of heart rate on the Doppler measurements of left ventricular function and to determine the normal pattern of rate dependency.**

***Setting*—University hospital specialising in internal medicine.**

***Participants*—14 healthy male volunteers 10 of whom were studied.**

***Intervention*: Transoesophageal atrial pacing.**

***Main outcome measures*—At paced rates of 70, 80, and 90 ppm the ratio of early to late peak transmitral flow velocity (E/A) was 1·97 (0·28), 1·49 (0·21), and 0·95 (0·11) respectively; the ratio of early to late time-velocity integrals of transmitral flow (Ei/Ai) was 3·03 (0·51), 2·11 (0·24), and 1·14 (0·30) respectively; and the atrial filling fraction (AFF) was 0·17 (0·03), 0·21, (0·04), and 0·24 (0·04) (mean (SD)).**

***Results*—Heart rate showed a linear correlation with E/A (r^2 = 0·806), Ei/Ai (r^2 = 0·838), and AFF (r^2 = 0·343). Neither the peak aortic flow velocity or the mean aortic flow acceleration showed significant changes during pacing at rates of 70, 80, 90, and 100 ppm.**

***Conclusions*—E/A and Ei/Ai can be expected to decrease by 0·5 and 0·9 for each increase of 10 beats/min in heart rate.**

Knowledge of this relation may be useful for the development of algorithms to correct for heart rate when diastolic function is assessed.

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Doppler echocardiography is a useful non-invasive procedure for evaluating left ventricular systolic[1 2] and diastolic[3 4] functions. Physiological variables, including the heart rate, affect cardiac performance and Doppler measurements.[5 6] However, the normal pattern of heart rate dependency of those measurements is still unclear. Clarification of the relation between the heart rate and left ventricular performance in healthy individuals would allow the application of echocardiography to be refined. We studied the influence of alterations in heart rate on Doppler indices of left ventricular performance.

Subjects and methods

STUDY POPULATION

We recruited 14 healthy male volunteers; four were excluded because of intolerable discomfort caused by pacing, unsatisfactory Doppler recordings, or a high sinus rate. The remaining 10 men (aged 25–30 (27·2 (1·7)) were free of illness as determined by their history and physical examination as well as by 12 lead electrocardiogram and echocardiogram. We obtained informed consent before the study. The men were fasting, non-sedated, and were receiving no medications at the time of the study.

TRANSOESOPHAGEAL ATRIAL PACING

A 6F quadripolar pacing catheter was passed through the nose and into the oesophagus. The distal or proximal pair of electrodes was used for bipolar pacing and the other pair for monitoring. The initial position was determined as reported by Benson *et al.*[7] Final positioning of the electrode was accomplished by electrocardiographic monitoring during electrode adjustment to obtain consistent left atrial capture. Stable capture required 15 ms pulses of 10 to 22 mA intensity provided by the pacing device (BC02 and BC02EP, Fukuda Denshi, Tokyo, Japan). After electrode placement, the men rested for at least 10 minutes to stabilise heart rate and blood pressure. Echocardiography was subsequently performed at the resting heart rate and was repeated at each paced rate. Atrial pacing was started at a paced rate of 70 ppm. We then increased the rate of atrial pacing by 10 ppm to a maximum of 100 ppm. To ensure haemodynamic stabilisation at each paced rate we waited three minutes before the echocardiogram was recorded. A 12 lead electrocardiogram was also recorded at each paced rate.

ECHOCARDIOGRAPHIC STUDY

Echocardiography was performed with the subject in the supine or left lateral position. A commercial phased array imaging system (SSH 160A, Toshiba, Tokyo, Japan) with pulsed wave and continuous wave Doppler capabilities was used. We used a 2·5 MHz imaging transducer for Doppler echocar-

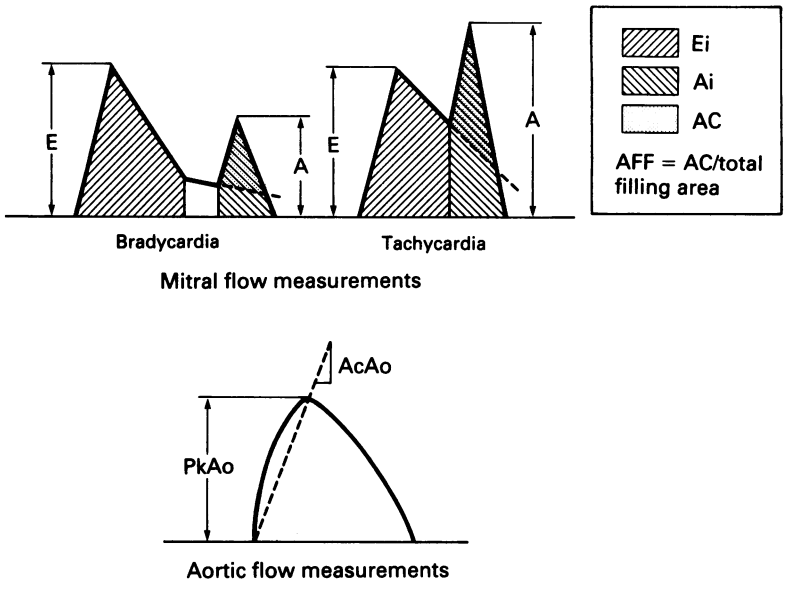


Figure 1 Peak early (E) and late (A) mitral flow velocities and early (Ei) and late (Ai) time-velocity integrals were obtained from the mitral flow velocity curve. The atrial filling fraction (AFF) was determined as the ratio of the area (AC) above the extrapolated line (broken line) from the passive filling wave to the total filling area. Peak aortic flow velocity (PkAo) and mean aortic flow acceleration (AcAo) were obtained from the aortic flow velocity curve.

diography and a 2·5 MHz non-imaging continuous wave Doppler transducer. Doppler recordings of mitral flow velocity were performed with the transducer at the cardiac apex. An apical four chamber view of the heart was used to align the Doppler cursor parallel with the apparent flow direction and the sample volume was placed at the level of the mitral annulus. Then the sample volume was moved slightly (with the aid of the audio signal and spectral display) to maximise the signal-to-noise ratio.

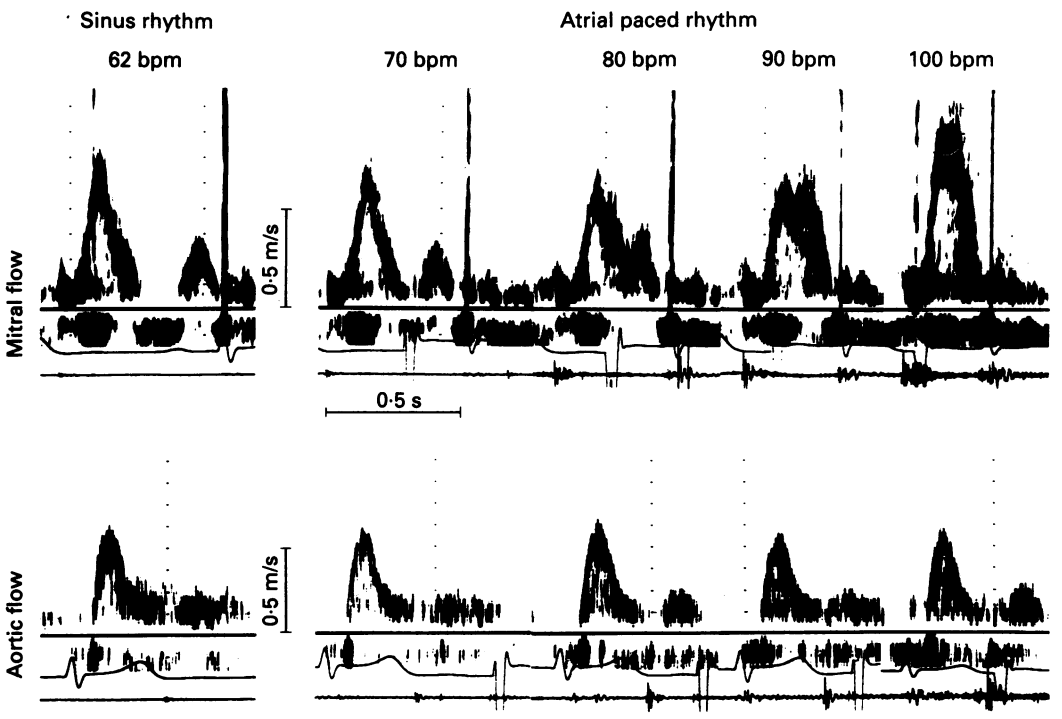
Aortic flow velocities were recorded from the suprasternal notch with a non-imaging transducer angulated to record the maximal flow velocity signal in the ascending aorta.

Doppler signals were recorded on a strip chart at a paper speed of 100 mm/s. The following measurements were obtained from the recordings as shown in fig 1. The mitral flow velocity curve was characterised by the early filling wave (E wave) and late filling wave (A wave). The peak flow velocities of an E wave (E) and an A wave (A) were measured and the E/A ratio was calculated. The time-velocity integrals of an E wave (Ei) and an A wave (Ai) were measured as the area under those flow velocity curves and the Ei/Ai ratio was also calculated. The atrial filling fraction (AFF) was determined by the method of Kuo *et al.*[8] This index was measured as the ratio of the area above the extrapolated line from the passive filling wave (AC) to the total filling area. The peak flow velocity (PkAo) and the mean acceleration from the onset of ejection to PkAo (AcAo) were measured from the aortic flow recording. Each measurement was obtained as a mean value of five consecutive beats to correct for beat to beat variation in the observed values. The mean coefficients of variation of the five observed measurements of the E, A, and PkAo at resting sinus rhythm were 5, 12, and 3%, respectively.

STATISTICAL ANALYSIS

Values are expressed as mean (SD) in the text and as mean (SEM) in the figures. The relation between the measurements and heart rate was analysed by analysis of variance. We obtained the regression line as well as the coefficient of determination (r^2), which was the ratio of the variance associated with the linearity (S_{Lin}) to the total variance of the measurement. The ratio of the S_{Lin} to the variance related to the changes in heart rate (r'^2) was also obtained as an index of the

Figure 2 Doppler recording obtained from a representative subject.



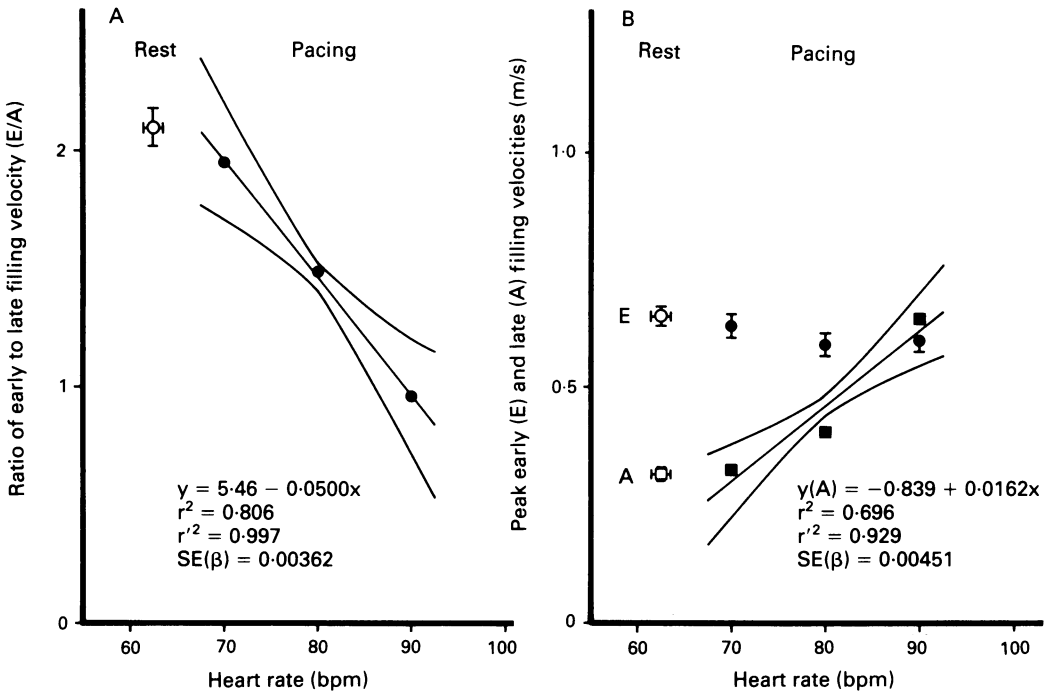


Figure 3 Relation between heart rate and E/A (A), E (circles), and A (squares) (B). The curvilinear lines indicate the 95% confidence interval for the regression lines for a particular point. r^2 = coefficient of determination; r'^2 = coefficient of the linearity of the relation between heart rate and the measurement; SE(β), standard error of the slope of the regression line.

linearity of the relation between the heart rate and the measurement without the influence of other factors, including the intersubject variance and the error. A p value $<0{\cdot}05$ was regarded as significant.

Results

Before pacing the mean heart rate was 62·6 (3·3) bpm. The mean resting systolic and diastolic blood pressures were 125·3 (5·7) and 70·6 (8·3) mm Hg. No abnormalities, including ischaemic ST changes, were seen in the 12 lead electrocardiogram during the study.

Figure 2 shows mitral and aortic Doppler recordings from one man. The transmitral flow pattern apparently changed with increasing heart rate whereas the aortic flow changed only slightly. Data from all the men were analysed as follows.

EFFECT OF ATRIAL PACING ON MITRAL FLOW

An increase in heart rate reduced the E/A ratio (fig 3A). There was an inverse linear relation during pacing (E/A = 5·46 − 0·0500 × HR (bpm) (r^2 = 0·806, r'^2 = 0·997). Mean values of A during pacing were also significantly affected by a change in heart rate. A was positively correlated with heart rate (A (m/s) = −0·839 + 0·0162 × HR (bpm) (r^2 = 0·696, r'^2 = 0·929). This relation was somewhat curvilinear. The fact that the variance in the non-linear part of this relation was significant (p

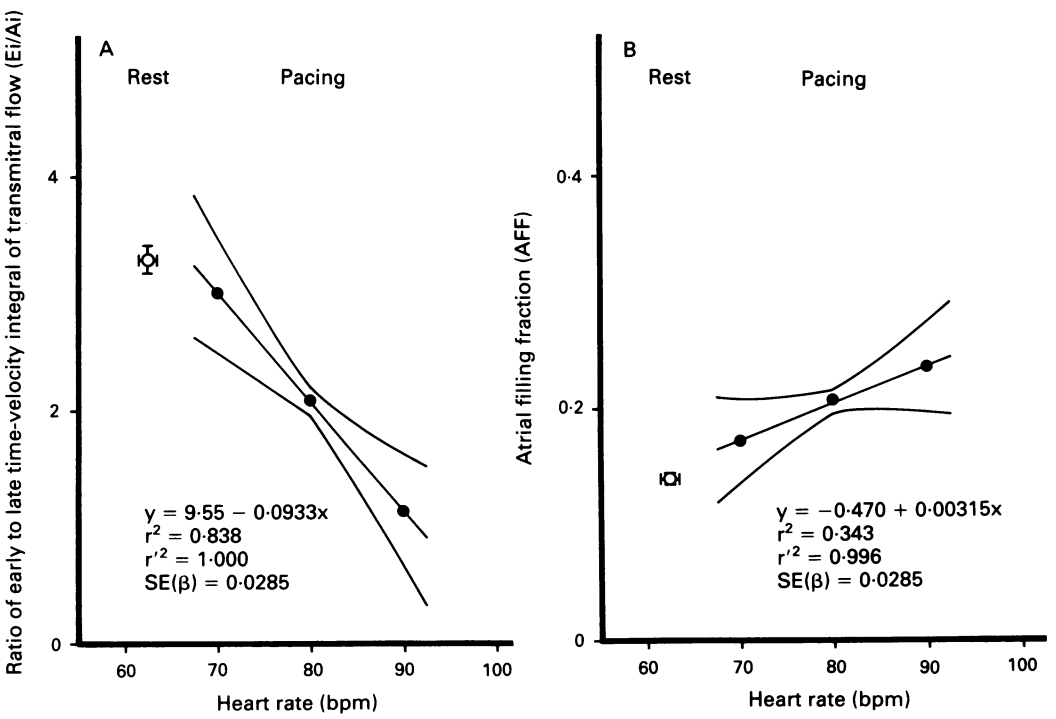


Figure 4 Relation between heart rate and Ei/Ai (A) and AFF (B). See legend to fig 3 for abbreviations.

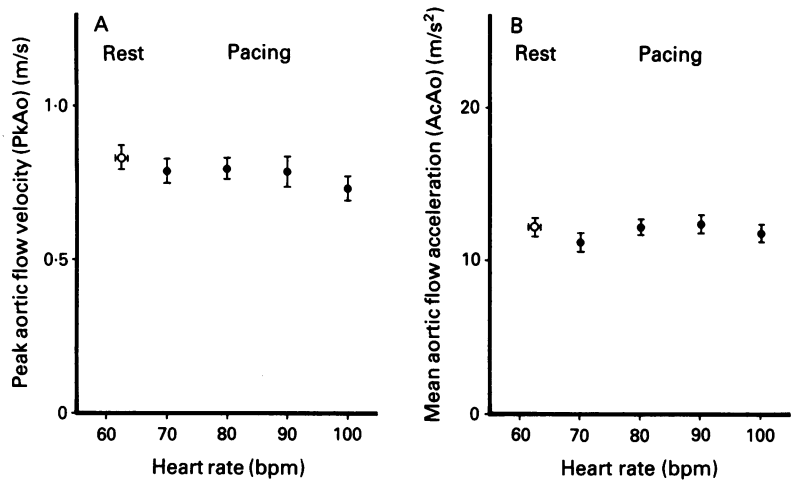


Figure 5 Relation between heart rate and the PkAo (A) and AcAo (B).

< 0·05) compared with the residual variance supported this observation. E, however, did not change significantly with an increase in heart rate (fig 3B). As with the time-velocity integrals, the Ei/Ai ratio was negatively correlated (Ei/Ai = 9·55 −0·0933 × HR (bpm), r^2 = 0·838, r'^2 = 1·000) and AFF was positively correlated (AFF = −0·0470 +0·00315 × HR (bpm), r^2 = 0·343, r'^2 = 0·996) with heart rate (fig 4). The AC showed no significant change with pacing rate. An increase in the heart rate to 100 ppm during atrial pacing resulted in overlapping of the A and E waves so that the Doppler indices of mitral flow could not be determined.

EFFECT OF ATRIAL PACING ON AORTIC FLOW

No significant changes in mean values of PkAo and AcAo were seen with increasing heart rate (fig 5).

Discussion

Doppler echocardiography provides blood flow velocity measurements, and various Doppler-derived indices have been used to evaluate cardiac function.[9,10] However, Doppler echocardiography cannot be simply applied to individuals because those indices can be influenced by various physiological variables. We found linear relations between heart rate and E/A, Ei/Ai, and AFF in 10 healthy young men. This provides a basis for correcting the Doppler-derived indices of left ventricular diastolic function.

MITRAL FLOW VELOCITY MEASUREMENTS

There have been some reports of the effects of heart rate on the diastolic measurements obtained with Doppler echocardiography. Gillam *et al* reported that an increase in heart rate increased the A and decreased E, E/A, and Ei/Ai in the patients with pacemakers.[11] Herzog *et al* showed similar results in patients undergoing cardiac catheterisation.[12] These results suggest that an increase in heart rate may lead to an increase in flow velocity and volume during atrial systole. However, few such studies have been conducted in healthy individuals. Smith *et al* studied the effects of increased heart rate and blood pressure caused by cold immersion in normal volunteers.[13] However, the effect of cold immersion can be attributed to the sympathetic nerve stimulation which may change cardiac function as well as heart rate.[14,15] Harrison *et al* studied the differences between the E, A, and E/A at a resting heart rate with sinus rhythm and at a heart rate of 90 bpm during transoesophageal atrial pacing.[16] They reported that pacing increased A and reduced E/A. Van Dam *et al* studied the relation between the E/A and resting heart rate and age in healthy volunteers and reported that a higher heart rate was associated with a lower E/A.[17] As the Doppler indices of diastolic function, including the E/A, Ei/Ai and AFF depend on the heart rate, their application to individual subjects requires knowledge of the pattern of their rate dependency. We studied the pattern of the dependency in young healthy men with normal diastolic function.

We found that heart rate correlated closely with E/A and Ei/Ai. Furthermore, because the relation was linear it may be useful in the development of algorithms that will correct for heart rate and enhance the non-invasive assessment of diastolic function in individuals. The pattern of dependency also needs to be studied in individuals with impaired diastolic function.

In addition, the apparent increase in A and in Ai may be attributed to the effect of the superimposition of the A wave onto the descending limb of the E wave. Pearson *et al* reported that PR prolongation increased Ai and that the effect might be caused by superimposition.[18] We too suggested that superimposition might be important in the effect of heart rate on Ei/Ai.[19] The fact that AFF showed only a weak correlation and AC showed no significant correlation with heart rate in the present study supports this concept.

Our present study had some limitations. There was a small but significant increase in the interval between the pacing artefact and the QRS complex (187 (14), 207 (15), and 217 (19) ms at paced rates of 70, 80, and 90 ppm, respectively). Because an increase in PR interval (as well as an increase in heart rate) causes more superimposition, the effects of changes in heart rate may have been enhanced in the present study.

AORTIC FLOW VELOCITY MEASUREMENTS

Aortic flow velocity and acceleration are known to reflect the left ventricular systolic function.[1,2] Some investigators have studied the effects of heart rate on aortic flow measurements. Wallmeyer *et al* reported that the peak aortic flow velocity as well as the mean acceleration of aortic flow showed a strong correlation with the max dP/dt and max dQ/dt and was independent of the heart rate in dogs.[20] On the other hand, Harrison *et al* in a study of healthy volunteers found an inverse relation between the heart rate and peak aortic flow velocity and acceleration.[5] They attributed this to a decrease in the end diastolic volume caused by the increased heart rate. We found no relation between aortic flow measurements and heart

rate. Harrison *et al* compared the aortic flow measurements at the resting heart rate and at heart rates of from 90 to 150 ppm during atrial pacing, whereas we used paced rates of from 70 to 100 ppm. At these low rates a change of heart rate may produce only minimal changes in the Doppler-derived systolic measurements. The relation between heart rate and measurements of aortic flow and mitral flow in health and disease should be further investigated.

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